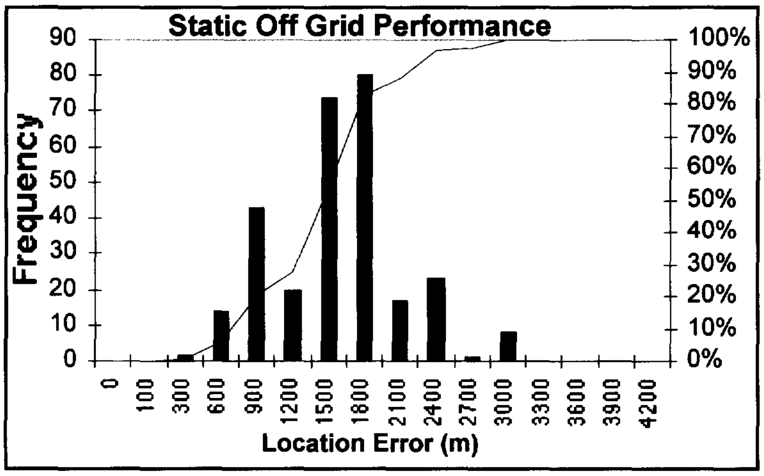
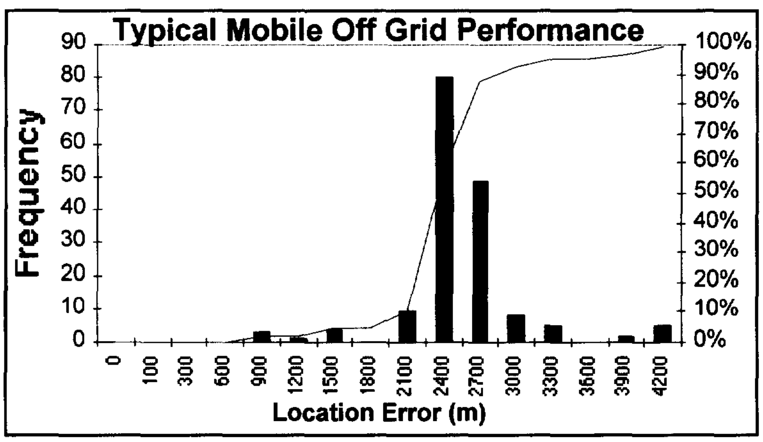
coverage makes triangulation solutions problematic because any valid location calculation requires coverage from at least three sites.

Performance of the US Wireless network-based technology in rural areas was measured by conducting several off-grid tests. These tests demonstrated extremely poor accuracy in these areas. Typical off-grid performance was 1800 meters for 73 percent of *fixed* calls (Figure 1) and 2400 meters for 51 percent of *mobile* calls (Figure 2).



- Figure 1 -- Typical static off grid performance.



- Figure 2 -- Typical mobile off grid performance.

This reduction in location accuracy is common to all network based location systems in areas with large cell site conditions. For calibration-based systems, the error increases as one moves farther away from the calibrated area. For angle of arrival-based systems, the error increases as one moves farther away from the site and the angular error becomes a larger position error. For time difference of arrival-based systems, the error increases as geometry of widely dispersed sites makes triangulation more difficult. The conclusion was clear: a network-based technology would not comply with the Commission's rules in Western's rural service areas.

Montana Wireless E9-1-1 Trial

Montana Wireless E9-1-1 Trial: Final Report

Released by:

State of Montana Department of Administration, Information Services Division

22 May 2000

Participants:

- Billings 9-1-1 Center
- Combix Corporation
- Nortel Networks
- State of Montana 9-1-1 Program
- U.S. WEST Inc.
- U.S. Wireless Corporation
- Western Wireless Corporation
- Williams Communications Solutions
- XYPOINT Corporation

ACKNOWLEDGEMENTS

The State of Montana Department of Administration, Information Services Division, is pleased to release the report detailing the results of the Billings, Montana Wireless Enhanced 9-1-1 trial. This was the first trial in the nation to use the RadioCamera™ location technology, provided by US Wireless Corporation, for 9-1-1 calls made from a wireless phone.

Although Montana has achieved 100% coverage with basic 9-1-1 service, currently only a few major population centers, and a rural area encompassing four rural counties in the northeast corner of the state, provide enhanced 9-1-1 (E9-1-1) service for wireline phones. The remaining 9-1-1 jurisdictions in the State are planning for E9-1-1, and there has been much discussion about the need for location information for wireless 9-1-1 calls as well.

The Federal Communications Commission addressed these concerns by issuing a Report and Order in Docket 94-102 in June 1996. Although there was a great deal of interest in the technologies under development for providing both Phase I and Phase II of the FCC's Report and Order, there was some concern in Montana that the location technologies being tested in other areas of the country would not work well in the rural areas of Montana, since they require three or more cell sites to provide location information with an accuracy of at least 100 meters for 67% of the calls.

Montana is a large and very rural state, with an area of approximately 147,000 square miles and a population of slightly over 850,000. The 9-1-1 community was concerned that technologies requiring more than one cell site to provide accurate location information would not work well in places where one cell tower serves a large geographic area. We were excited to learn about an emerging location technology that could possibly provide location information using one cell site.

The area selected for this trial covered approximately 25 square miles and included downtown Billings and surrounding residential, industrial and suburban/rural regions. As the attached report shows, the RadioCamera™ was able to locate the caller for over 1800 test calls, and was successful in all environments. Although the test calls were made to "2-1-1" so as not to disrupt the operation of the Billings public safety answering point (PSAP), the results clearly show that this system has potential to assist 9-1-1 callers in both urban and rural areas.

The Montana 9-1-1 Program Section and the Billings Communications Center wish to thank the trial participants: Combix Corporation, Nortel Networks, US West Communications, US Wireless Corporation, Western Wireless Corporation, Williams Communications Solutions, and XYPOINT Corporation. We feel very fortunate that these organizations were willing to conduct this trial project in Montana. This group worked very hard to make the project a success.

All of the participating industry organizations and government agencies gave freely of their employees' time and provided the necessary equipment, network/switching capabilities, and other resources, at no cost to the State or to the Billings Communications Center, required to get the trial underway and bring it to a successful conclusion. A description of the participants' roles is provided in Section 1.1 of the attached report. The Montana 9-1-1 Program Section is proud to have been a part of this effort.

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1 INTRODUCTION & EXECUTIVE SUMMARY

This report describes the recently completed Montana Wireless E9-1-1 Trial conducted in Billings, Montana during the nine-month period from December 1998 through August 1999. The purpose of the Montana trial was to design, deploy, and evaluate an operational end-to-end wireless E9-1-1 system capable of meeting and exceeding the requirements for locating wireless 9-1-1 callers, as established by the FCC 94-102 mandate. A team of nine government and industry organizations participated in the trial, resulting in the successful deployment of a system providing service for a 25 square mile region serving the greater Billings, MT area. The location technology under evaluation was the RadioCamera™ wireless location system provided by US Wireless Corporation. The RadioCamera™ system was integrated with the existing wireless, wireline, and 9-1-1 infrastructure to provide an overall system capable of locating callers upon call initiation, properly routing the call to the closest 9-1-1 center, and providing continuous caller location updates[1] throughout the duration of an emergency call. The system performance was evaluated in an operational mode in which the caller's location, callback number, and address were displayed and continuously updated on the 9-1-1 call-taker's screen. In addition to the location technology evaluation, the Billings 9-1-1 Center and the State of Montana 9-1-1 Program office compiled statistics on the nature of 9-1-1 calls received during the trial to assess requirements and benefits of having accurate caller location information and callback numbers.

1.1 Trial Participants

The trial participants included multiple industry and government organizations that provided all necessary resources to complete the system design, deployment, and evaluation. A description of the principal trial participants and their roles is as follows:

Billings 9-1-1 Center, *2303 8th Avenue N, Billings, MT 59101*
- Provided 9-1-1 center facilities and call-takers
- Conducted 9-1-1 call statistics survey & evaluation
- Participated in performance evaluation

Combix Corporation, *811 E. Plano Parkway, Suite 106, Plano, TX 75074*
- Developed enhanced mapping tools for continuous location display

Nortel Networks, *9597 Jones Road, Suite 144, Houston, TX 77065*
- Provided 9-1-1 Center customer premises equipment (CPE) - Meridian 1 PBX and Symposium ENR software and hardware

[1] The ability to continuously update 9-1-1 caller locations is not required under the current FCC Mandate, however this capability was deemed desirable for the Montana trial and was incorporated in the trial system.

State of Montana 9-1-1 Program, *Department of Administration, Information Services Division, RM 226, Sam W. Mitchell Building, Helena, MT 59620*
- Served as trial auditor
- Participated in performance evaluation
- Released the final report

US WEST Inc., *200 S. 5th Suite 1700, Minneapolis, MN 55369*
- Provided local exchange carrier facilities, including the Selective Router
- Customization of automatic number identification (ANI) and automatic location identification (ALI) database to support Phase II with location updates

US Wireless Corporation, *2303 Camino Ramon, Suite 200, San Ramon, CA 94583*
- Provided RadioCamera™ wireless location system
- Project management
- Participated in performance evaluation

Western Wireless Corporation, *2000 Coburn Road, Billings, MT 59101*
- Provided wireless carrier facilities
- Hosted the RadioCamera™ location system at cell sites
- Participated in performance evaluation

Williams Communications Solutions, *50 S. Last Chance Gulch, Suite 2, Helena, MT 59601*
- Provided 9-1-1 Center telecommunications equipment
- Installation and configuration of Nortel PBX

XYPOINT Corporation, *2825 Eastlake Avenue, Seattle, WA 98102*
- Provided 9-1-1 network services (installation & operation)
- Provided FCC Phase I location services
- Participated in performance evaluation

While not an official trial participant, **SCC Corporation** played a substantial role in modifying and managing the ANI/ALI database during the trial, and in facilitating the introduction of advanced caller location updating capabilities.

1.2 System Performance Summary

The trial system performance evaluation was conducted in three stages, each of approximately one month in duration. The formal evaluation period took place from 27 May 1999 through 28 August 1999, and was audited by representatives from the State of Montana 9-1-1 Program office. The primary performance metrics included (1) location accuracy, and (2) routing latency. Location accuracy was characterized in terms of the accuracy achieved for 67% of all location measurements[2]. Routing latency was defined as the increased call set up time required to properly route the call based on the first location measurement. A summary of the overall system performance is provided in Table 1. A total of 1800 test calls were placed, resulting in 29,970 location fixes. More comprehensive performance results, test methodologies, and system descriptions are presented later in this report.

Table 1: Summary of location accuracy and latency performance.

Test Stage	No. of Calls	No. of Fixes	Latency (s)	Accuracy (m)
1	642	9,244	1.18 seconds	98.5 meters
2	586	9,124	1.29 seconds	110.6 meters
3	572	11,602	1.14 seconds	85.7 meters

The system performance achieved during the trial surpassed FCC accuracy requirements and was able to properly route the calls to the 9-1-1 center quickly and accurately.

Results from the 9-1-1 call survey conducted by the Billings 9-1-1 Center staff indicate:

- 18% of 9-1-1 callers did not know their location
- 29% of 9-1-1 callers did not know their callback number (cell phone number)
- 85% of the 9-1-1 calls required knowledge of the caller's location for proper dispatch of response personnel
- 12% of the 9-1-1 calls required use of the callback number

In addition, the following statistics were compiled related to the mobility of the 9-1-1 callers, as reported by the callers:

- 73% of 9-1-1 callers were mobile at the time of the call
- 14% of 9-1-1 callers were stationary at the time of the call
- 13% of 9-1-1 callers did not have their mobility recorded (unknown)

1.3 Report Organization

In Section 2, an overview of the RadioCamera™ wireless location system technology is provided. In Section 3, the overall trial system is described, including the basic architecture and call flow processing. In Section 4, the test methodology is described, including test environments, test equipment, and call procedures. In Section 5, comprehensive performance analysis is provided for each of the test environments and target operating conditions. In Section 6, results of the Billings 9-1-1 Center call survey are then presented. In Section 7, final conclusions are presented.

2 At the time of the trial, the FCC mandate required 125-meter RMS location accuracy (approximately 67% of all calls were to be located within 125 meters). In September 1999 the FCC modified these requirements to include location accuracy within 100 meters for 67% of the calls, and 300 meters for 95% of the calls. As such, only the 67th percentile results are available for this trial and report.

2 LOCATION TECHNOLOGY

The location technology selected for evaluation in the Montana Wireless E9-1-1 Trial was the RadioCamera™ wireless location system, provided by US Wireless Corporation. The RadioCamera™ system is one of a class of location systems referred to as "network overlay" systems, implying that the location measurement is performed by a separate set of infrastructure that overlays the wireless cellular or PCS network. As such, the system is able to locate all wireless callers within the network, including those callers roaming into the coverage area from other networks. No modification to a caller's handset is required for this technology; therefore all new handsets as well as legacy (pre-existing) handsets are able to be located in the event of a 9-1-1 call. One of the primary reasons for selecting the RadioCamera™ system was the ability of the system to locate 9-1-1 callers in a variety of challenging environments and wireless network conditions found in the state of Montana. Of particular interest was the ability of the system to locate a caller in those rural environments in which only one cell tower is available to "hear" the call. Under such conditions, alternative triangulation-based location systems may perform poorly or fail altogether.

2.1 Location Pattern Matching

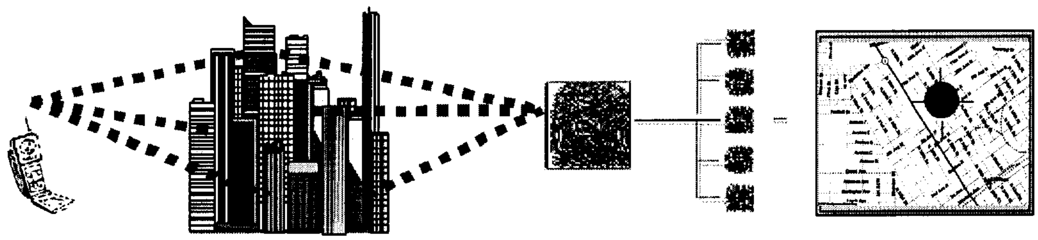
The RadioCamera™ system employs a location technology known as Location Pattern Matching. This technology was developed to address challenges associated with locating wireless callers in urban environments, where line of sight between a wireless subscriber and multiple cell towers may be obstructed, and in rural environments where there may not be enough cell towers to perform conventional triangulation. Additionally, the subscriber's radio signal in most environments reaches the cell towers via multiple paths, bouncing off various man-made and natural obstacles. This phenomenon is referred to as *multipath*, and may also be problematic for more conventional location methods.

The basic principle of the RadioCamera™ system operation is that it is possible to measure and characterize the complex multipath patterns received from a wireless caller and to form a direct correlation between these unique patterns (or signatures) and the caller's geographic location.

The RadioCamera™ system incorporates proprietary techniques for analyzing and categorizing these multipath patterns. A broad set of signal characteristics is taken into consideration in this process including the relative power, direction of arrival, time-of-arrival, and number of dominant reflections contained in the multipath profile. In order for the RadioCamera™ system to learn these patterns and to associate them with unique geographic locations, the system must be trained using standard drive test procedures similar to those employed in wireless networks. This training produces a look-up table of signatures that is then used to locate all callers operating in the system's coverage area.

Once the system has been trained, the location process is very straightforward. This process is described in Figure 1.

Figure 1: The RadioCamera™ location pattern matching process.



1. A call placed from a mobile cell phone emits radio signals.	2. The signals bounce off of buildings and other obstacles, reaching the system antennas via multiple paths.	3. The RadioCamera™ analyzes the unique characteristics of the signal, including its multipath pattern, and compiles a signal pattern signature.	4. The signature is compared to a database of signatures from known locations, and a match is made.	5. By matching the signature of the caller's signal pattern with signatures from known locations, the caller's geographic location is identified.

2.2 The RadioCamera™ System Architecture

The RadioCamera™ system architecture is similar to that of a cellular or PCS network. The system is comprised of two basic components: a collection of RadioCamera™ Base Units (RBUs) and a Network Operating Center (NOC). The RBUs measure the wireless signals, create the location signatures, and determine the caller's location. The NOC consists of a number of processors networked to the collection of RBUs. The software running at the RNOC completely controls all RBU's, directing their activity, receiving and storing location information, and monitoring RBU performance and operation. In addition, the NOC also provides the location information to the end user – in this case, a 9-1-1 call center. The RadioCamera™ system architecture is shown in Figure 2.

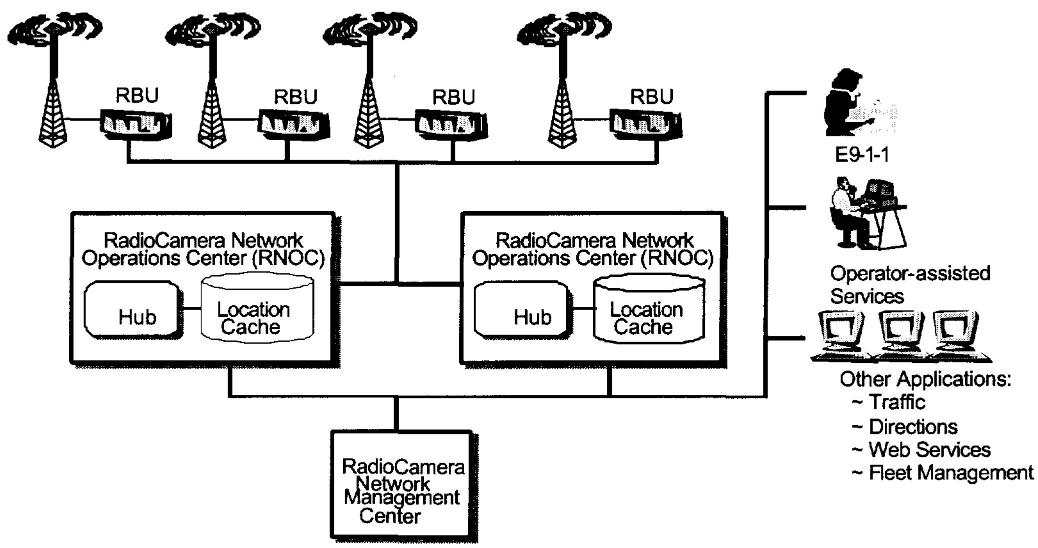


Figure 2: The RadioCamera™ system architecture.

3 TRIAL SYSTEM

The trial system architecture chosen for the Montana Wireless E9-1-1 Trial was a Non Call-Associated Signaling (NCAS) architecture, as defined in the Telecommunications Industry Association (TIA) PN3890 standard. This architecture supports a call flow in which the voice is transported through the network along one path, while the supplementary location and callback number information is transported through a separate path. This architecture was chosen for two reasons: (1) it is the quickest to implement, and (2) it requires minimal modification to existing Public Safety Answering Point (PSAP) infrastructure or communications trunks. The latter consideration allowed the trial to progress with minimal changes to the Billings 9-1-1 Center, and enabled the overall system to continue to use existing CAMA trunks for intersystem communications, rather than upgrading to Feature Group D (FG-D) trunks or a wireless intelligent network solution. This architecture was desirable since the majority of existing 9-1-1 infrastructure in Montana is based on CAMA signaling and is not scheduled to be upgraded soon. The overall system architecture is shown in Figure 3.

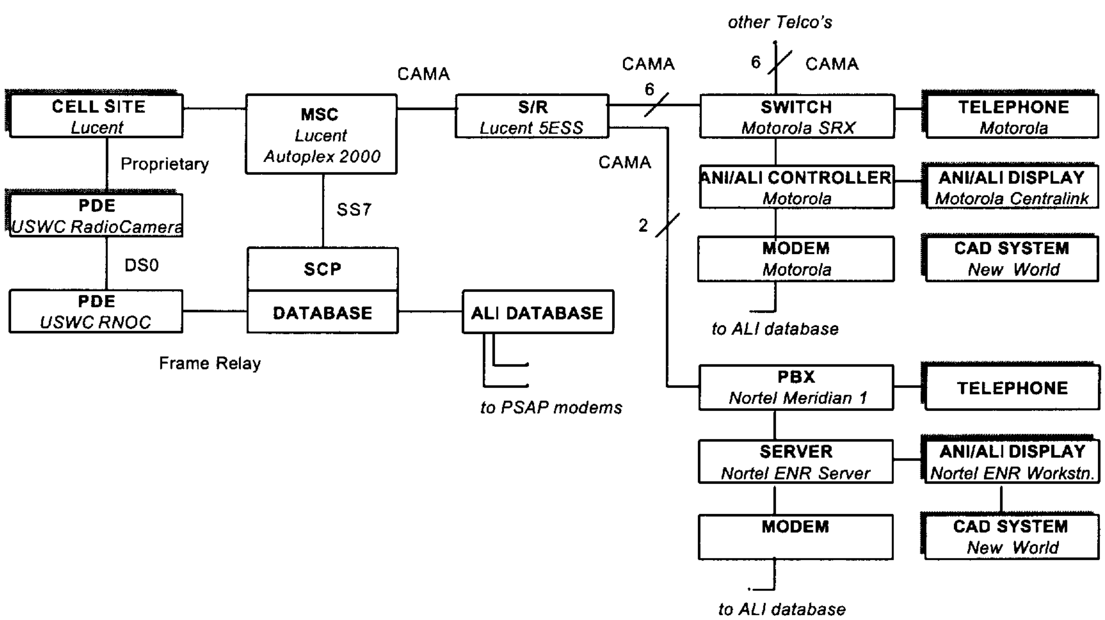


Figure 3: Montana Wireless E9-1-1 Trial system architecture.

The wireless system infrastructure was provided by Western Wireless Corporation and consisted of Lucent base station equipment and a Lucent Autoplex 2000 at the Mobile Switching Center (MSC). The RadioCamera™ Base Units (RBUs), provided by US Wireless Corporation, were collocated at 5 Western Wireless cell sites and shared antennas and power. The RBUs were connected to the RadioCamera™ NOC using 56Kbps DS0 links provided by Western Wireless. XYPOINT Corporation provided a gateway to the Signaling System 7 (SS7) network via a Service Control Point (SCP) entity and a call routing database. The XYPOINT system communicated with the RadioCamera™ NOC through a Frame Relay link and was connected to the SS7 cloud in order to support communications with the wireless system MSC. In addition, the XYPOINT system was connected to the ALI database owned by US WEST, and operated by SCC. US WEST also provided a Lucent 5ESS Selective Router (S/R) to enable the 9-1-1 calls to be routed based on caller location. The S/R was connected to both the MSC and the PSAP by standard CAMA trunks. At the Billings 9-1-1 Center, the operational portion of the 9-1-1 system was left unchanged. A supplementary E9-1-1 test system was installed in the PSAP Emergency Operations Center (EOC) and consisted of equipment provided by Nortel Networks and Williams Communications Solutions. This equipment included a Nortel Meridian 1 PBX (Option 11) with an ANI/ALI controller and a complete Nortel ENR workstation for ANI/ALI display, call handling, and computer aided dispatch (CAD). This equipment shared existing ANI/ALI modems and data links in use at the Billings 9-1-1 Center.

3.1 Phase I Call Flow

The call flow employed in the Montana Wireless E9-1-1 Trial is described in Figures 4 and 5, for FCC Phase I and Phase II capabilities, respectively.

The Phase I processing provides the PSAP with the location of the wireless cell site serving the call, as well as the caller's callback number. In the event of a failure in the Phase II location system, this processing serves as a backup to ensure that a rough location estimate and callback number is still available. Referring to Figure 4, Phase I call flow is described as follows:

1. The 9-1-1 voice call is transported from the serving cell site to the MSC;
2. The MSC recognizes that this cell site is in an area served by an enhanced location service and sends a message consisting of the Mobile Identification (MID) and serving cell site ID to the XYPOINT gateway;
3. The gateway assigns an 8-digit Emergency Services Routing Key (ESRK) based on the location of the serving cell site. This routing key will determine the destination PSAP and will also serve as an identifier for this specific 9-1-1 call. The ESRK is returned to the MSC via the SS7 network;
4. Simultaneous with Step 3, the gateway sends a message to the ALI database containing the MID, the location of the serving cell site, and the ESRK. The location is provided in both a latitude / longitude and address format;
5. The MSC now forwards the voice portion of the call and the ESRK on to the Selective Router via the CAMA trunks;
6. The S/R determines the proper outgoing CAMA trunks based upon the ESRK, and forwards the voice and ESRK on to the PSAP;

7. At the PSAP the voice is sent to a call taker and the ESRK is sent to the ALI database, requesting that the additional call data be returned;
8. In response to the PSAP ALI "bid", the database returns the ESRK, the callback number, the serving cell site coordinates (latitude & longitude), and the cell site address. This information is formatted and displayed on the appropriate call taker's CAD screen, in both textual and graphic form.

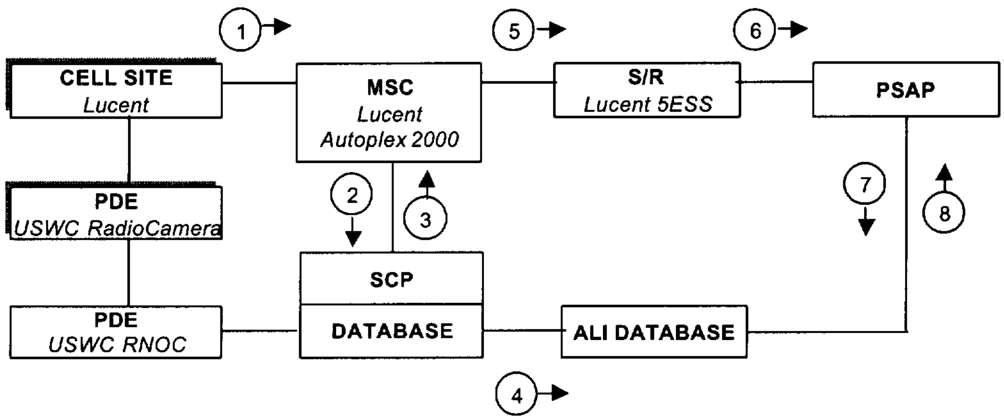


Figure 4: Montana Wireless E9-1-1 Trial FCC Phase I call flow diagram.

3.2 Phase II Call Flow

Referencing Figure 5, the Phase II call flow is described as follows:

1. The 9-1-1 voice call is transported from the serving cell site to the MSC;
2. Simultaneously, the RadioCamera™ Base Units detect that a 9-1-1 call has been initiated and determines the location of the caller;
3. The location measurements from one or more RBUs are sent to the RNOC where a final location determination takes place;
4. The MSC recognizes that the serving cell site is in an area served by the location service and sends a message to the XYPOINT gateway consisting of the Mobile Identification (MID) and serving cell site ID;
5. The gateway determines that this specific cell site is located within the RadioCamera™ coverage area, and forwards a request the RNOC to supply the exact location of the caller. This request contains the MID and serving cell site information;
6. Based on the MID, the RNOC returns the caller location coordinates (latitude & longitude) and the associated MID;

7. Using the caller location coordinates, the gateway determines the proper PSAP and assigns a corresponding ESRK. The 8-digit ESRK is returned to the MSC via the SS7 network;
8. Simultaneous with Step 7, the gateway sends a message to the ALI database containing the MID, the location of the serving cell site, the ESRK, and the coordinates of the caller, as determined by the RadioCamera™ system. The location coordinates are provided in both a latitude / longitude and address format;
9. The MSC now forwards the voice portion of the call and the ESRK on to the Selective Router via the CAMA trunks;
10. The S/R determines the proper outgoing CAMA trunks based upon the ESRK, and forwards the voice and ESRK on to the appropriate PSAP;
11. At the PSAP the voice is sent to a call taker and the ESRK is sent to the ALI database, requesting that the additional call data be returned;
12. In response to the PSAP ALI "bid", the database returns the ESRK, the callback number, the serving cell site coordinates (latitude & longitude), the cell site address, the caller location coordinates (latitude & longitude) and the caller address. In this case, the caller's address is given as an address range (e.g., 100-200 Main Street). All information is formatted and displayed on the appropriate call taker's CAD screen, in both textual and graphic form.

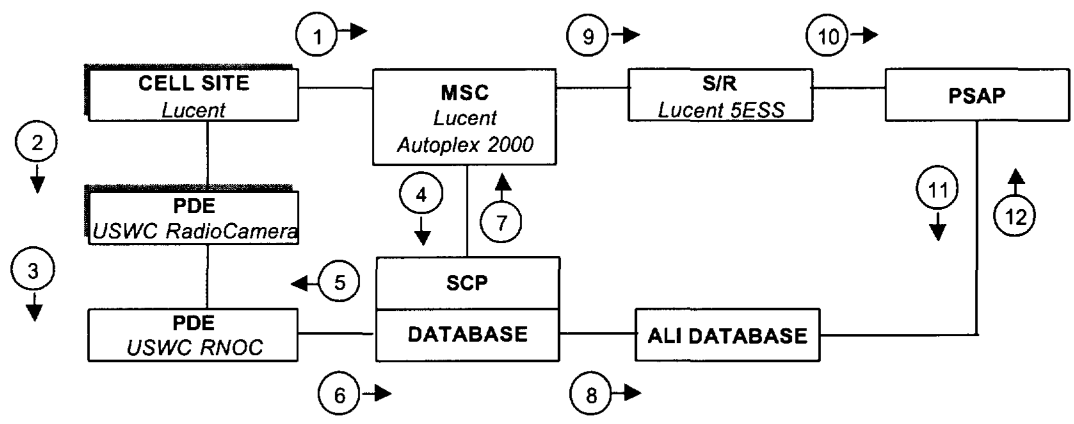


Figure 5: Montana Wireless E9-1-1 Trial FCC Phase II call flow diagram.

4 TEST METHODOLOGY

In this section, the Montana Wireless E9-1-1 Trial test methodology is described. First, a description of the test coverage area is provided, including details of the terrain, buildings, foliage, and clutter present. Next, the trial equipment is described, followed by a description of the test call procedures and performance measurement techniques. A detailed characterization of the data analysis procedures is deferred until Section 5.

The performance analysis portion of the Montana Wireless E9-1-1 Trial was divided into three test stages, each of approximately one month in duration. During each stage, an evaluation of system performance was conducted for a complete set of predetermined fixed test points and mobile test routes. Once a test stage began, the system was considered to be in an operational mode, and only minor modifications to the software, hardware, and configuration were permitted. This was done to ensure that an accurate "snapshot" of the system performance was being captured. Between stages, more substantial modifications were permitted to further optimize system performance.

4.1 Coverage Region & Test Environments

The coverage area selected for the Montana Wireless E9-1-1 Trial is shown in Figure 6. The test area encompasses approximately 25 square miles, including downtown Billings, MT and the surrounding residential, industrial, and suburban / rural regions. Within this coverage area, a total of 22 fixed test points and 9 mobile test routes were selected for the performance evaluation. These test points and routes were chosen to uniformly sample the test area and to provide a balanced cross section of the types of environments found in that region. The selected test points and mobile routes are shown in Figures 7 and 8 respectively. For purposes of evaluation and comparison, subsets of the test points and routes were combined to form four representative operating environments. These operating environments are defined as: (1) Light Urban, (2) Industrial, (3) Residential, and (4) Suburban / Rural. The specific fixed test points and mobile test routes that comprise each environment are described in Table 2. A characterization of each environment is provided in Table 3 in terms of the buildings, topography, clutter, roadways, and foliage present.

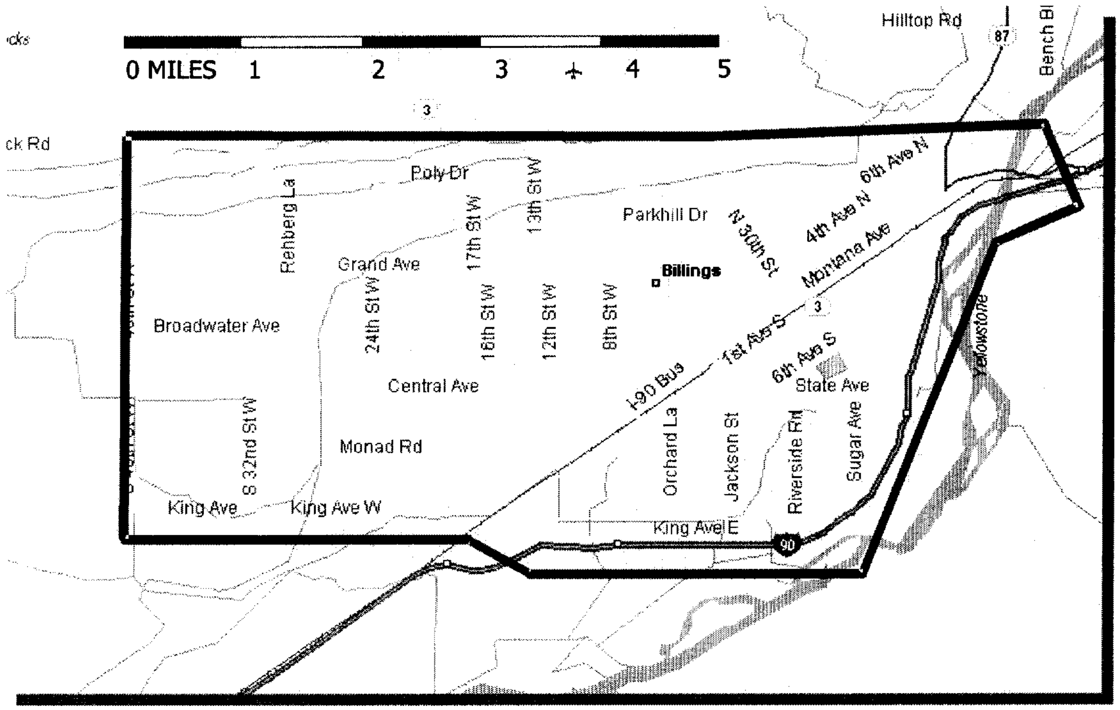


Figure 6: Montana Wireless E9-1-1 Trial test coverage area.

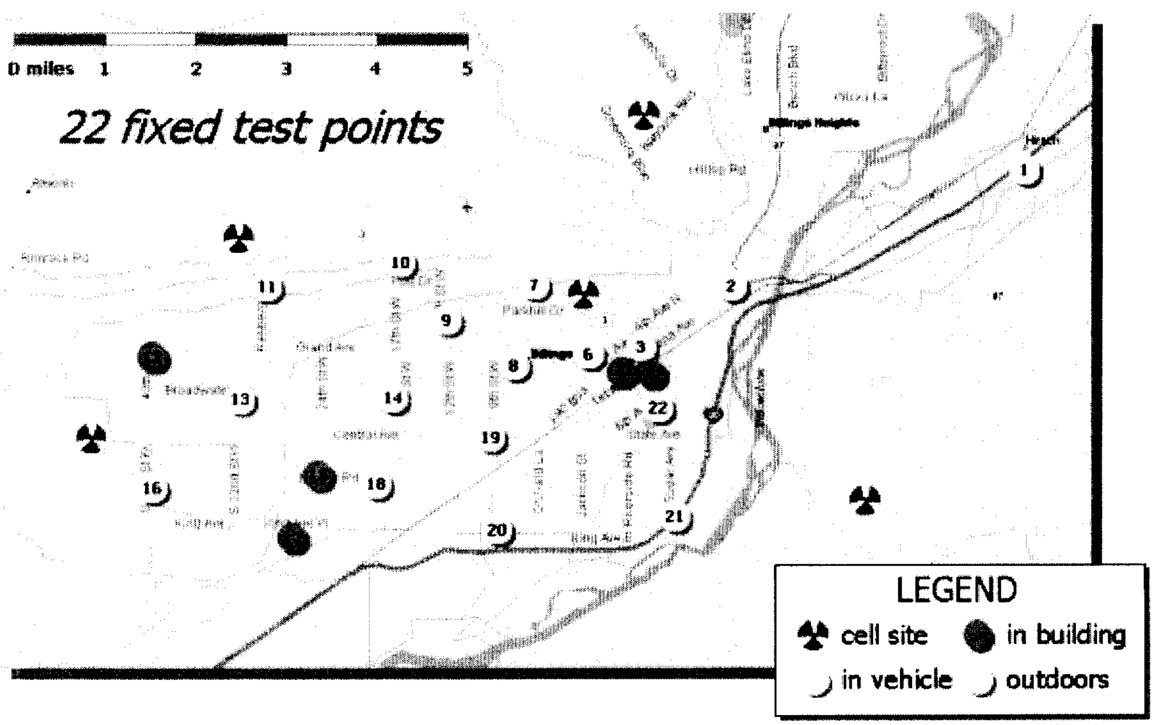


Figure 7: Twenty-two fixed test points selected for evaluation.

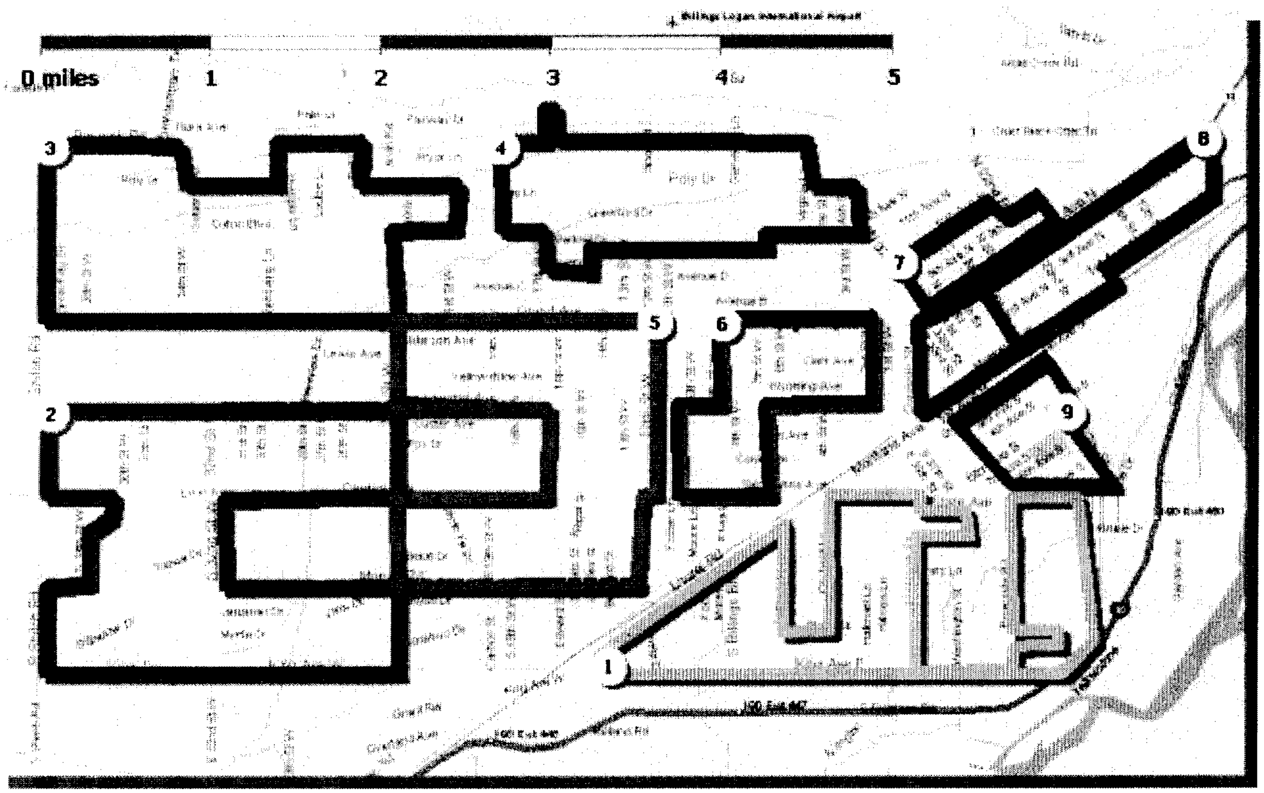


Figure 8: Nine mobile test routes selected for evaluation.

Table 2: Operating Environments - fixed test point and mobile test routes.

Environment	Fixed Test Points	Mobile Test Routes
Light Urban	3, 4, 5, 6	7, 8
Industrial	1, 2, 8, 15, 18, 19	5, 6, 9
Residential	7, 9, 10, 11, 14, 17, 22	2, 3, 4
Suburban / Rural	12, 13, 16, 20, 21	1

Table 3: Test Operating Environment descriptions.

Light Urban	
Buildings	Single-story to 27 story buildings, predominantly 3-15 stories. Primarily brick and stone structures. Mostly businesses, office buildings and hotels.
Topography	Generally flat.
Clutter	Elevated sidewalks, sculptures, traffic signals, traffic signs.
Roadways	Wide roads, 3-4 lanes primarily, many 1-way streets
Foliage	Minimal foliage, confined to perimeter area.
Industrial	
Buildings	1-3 story structures, oil refinery, fairgrounds / park area, primarily steel, brick and stone construction.
Topography	Near to northern rims (200' cliff), relatively flat with steep incline approaching cliffs.
Clutter	Refinery equipment, towers, tanks, stadium structure.
Roadways	Main streets are 4-5 lanes, side streets are 2 lanes
Foliage	Tall deciduous trees near park (100') and lining roads, minimal otherwise.
Residential	
Buildings	Mostly 1-2 story homes, apartment buildings, and some light business (gas stations, restaurants, etc.). Primarily wood structures, some ranch style homes, and trailer parks.
Topography	Generally flat, slight grade upwards to the west and north (140'), near to northern rims (300' cliff).
Clutter	High voltage transmission lines and towers, construction company with gravel piles and equipment.
Roadways	Primarily 2 lane roads with a 6-lane primary road.
Foliage	Young trees in some areas, tall deciduous trees lining older neighborhoods, moderate foliage in general, some evergreens.
Suburban / Rural	
Buildings	1-2 story ranch homes, some industrial structures, primarily wood construction.
Topography	Generally flat, near the Yellowstone River, within one mile of the southern rims (500' cliff).
Clutter	Railroad tracks/yards, livestock, sugar beet refinery, power plant, cooling towers.
Roadways	2-lane paved roads, 2-lane gravel roads.
Foliage	Moderate foliage, mature trees, open fields with sparse foliage.

4.2 Test Equipment

For the first and second test stages, the location system was comprised of four RadioCamera™ Base Units (RBUs) and a single Regional Network Operations Center (RNOC). A fifth RBU was added for the third stage of testing. In all cases, the RBUs were collocated with Western Wireless base stations, while the RNOC was located at the

Western Wireless MSC. The locations of the RBUs and RNOC can be seen in Figure 7. All RBUs employed the existing cellular antennas at each site, and were connected directly to the base station multicoupler port. Six omni-directional antennas were used at each site. Five Western Wireless cell sites serve the entire test region; therefore there was a one-to-one ratio of RBUs to cell sites.

The transmitters employed in testing were commercial 600mW portable cellular phones, with no modifications. Testing was done for AMPS phones only, with all test phones subject to normal power control and hand-off procedures.

For outdoor testing, a specially equipped vehicle was employed to accurately monitor and record the transmitter's true location. The position was determined using a differential GPS unit combined with an in-vehicle dead-reckoning system. GPS time was used to provide an accurate time-stamp for each position measurement. During testing, the vehicle's position was measured once per second, and recorded to a log file on a laptop computer. For indoor testing, all test point locations were computed based on distances from surveyed outdoor differential GPS reference points.

4.3 Call Procedures

For each stage of testing, multiple calls were placed at each of the fixed test points and mobile test routes. All test calls used the dialed digits 2-1-1, to avoid any conflicts with the existing E9-1-1 system and to minimize liabilities. For the fixed test points, the calls were approximately 30 seconds in length, and were repeated at least 7 times during each visit to a test location. The calls used for mobile testing were approximately 2 minutes in length, continuously placed throughout the duration of the drive test. For each test call, the location estimate was updated approximately every 2.5 to 4.0 seconds (a variable parameter). In total, there were 1800 test calls placed, resulting in 29,970 location fixes.

5 PERFORMANCE RESULTS

Performance was characterized in terms of two key metrics: (1) location accuracy, and (2) routing latency. Location accuracy was computed by comparing RadioCamera™ location estimates against the ground truth measurements recorded by the differential GPS / dead reckoning system. Routing latency was defined as the additional time added to the call setup time required to route the call based on the location information. This included the period of time from which the wireless switch initiated an outgoing IS-41 trigger requesting routing information, until that information was returned to the switch. During this time, the location system was queried for the location information, the proper routing was assigned, and the relevant information was sent to the ANI / ALI database. This includes completion of steps 4-8 in Figure 5 of Section 3. Note that in this trial, the RadioCamera™ system was deployed as a dedicated system sharing the wireless infrastructure, and not as an independent location system. As such, the overall accuracy performance of the system is somewhat less than would be expected in an independent deployment, due to limitations resulting from shared antennas, local interference, etc.

5.1 Stage I Results

Latency analysis for Stage I testing was conducted over the time period 27 May 99 through 22 June 99. The specific test periods used in this analysis are described in Table 4. Latency performance is characterized in terms of the average and 67th percentile performance and is summarized in Table 5 for each week of testing, as well as the overall performance for the entire stage of testing.

Table 4: Test periods for latency analysis – Stage I. All times are given in Central Standard Time.

Date	Start Time	End Time
27-May-99	22:40	23:59
28-May-99	0:01	6:07
28-May-99	8:53	11:33
3-Jun-99	14:50	16:58
10-Jun-99	12:02	16:43
10-Jun-99	18:16	20:07
11-Jun-99	9:37	12:50
11-Jun-99	14:47	15:06
16-Jun-99	9:27	16:49
21-Jun-99	13:38	16:38
22-Jun-99	9:37	15:18